

Design Consideration and Performance of Networked Narrowband Waveforms for Tactical Communications

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ABSTRACT

An air-interface architecture to ensure reliable signal acquisition and synchronisation for a narrowband networking waveform is presented. Simulation results show that a relatively simple preamble design can be used to ensure sufficiently reliable estimates of the unknown physical layer synchronisation parameters i.e. phase, frequency offset and timing errors. Results are presented comparing the error variance of the synchronisation parameters with the lower bounds for an unbiased estimator. The results enable system designers to select the operating noise tolerances for a given radio and modify the preamble architecture accordingly.

1.0 INTRODUCTION

Tactical communication systems operating in the UHF/VHF band have received considerable interest recently, in particular with the ongoing NATO (North American Treaty Organisation) standardisation of a new narrowband tactical networking waveform [1]. To meet the challenge of providing an air-interface architecture with improved range and throughputs compared to legacy waveforms, a physical layer design based on modern signal processing techniques which can provide good spectral efficiencies and operate in relatively low signal-to-noise ratio's (SNR's) is desirable. Further, to enable efficient use of the channel resources, a burst data communication system is commonly employed thus facilitating integration of network traffic for multiple users or nodes.

To reduce the network overhead in burst data communications, it is desirable for the on-air transmissions to be constructed in a manner whereby the receiver either blindly or automatically detects the data rate of the payload transmission, without a-priori information. In this manner, the transmitter and receiver can utilise throughputs optimised for the link SNR, or for the traffic load. To facilitate this design, a universal preamble may be used, whereby the preamble and header information are transmitted with a fixed data rate, modulation format and duration irrespective of the data rate or modulation parameters used in the payload data. In this scenario, a universal preamble greatly simplifies the receiver signal processing whilst maintaining equal power, bandwidth and preamble duration [2].

In the scenario outlined above, the requirements on the physical layer acquisition and synchronisation are relatively stringent. In particular, the receiver must acquire coarse estimates of the unknown parameters such as carrier frequency offset, phase offset, frame synchronisation and symbol timing parameters. The receiver must then apply the offset correction to the received signal and initialise the required tracking loops for phase and symbol timing. In addition, the latency requirements for the receiver processing of the burst data are also

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quite stringent, and are dictated by the operational requirements for the networking waveform. In this respect, low latency processing of both the preamble and payload portions of the waveform is desired. Reliable payload demodulation therefore depends on estimating the unknown parameters with sufficient accuracy at the desired operating signal-to-noise ratio with the additional constraint of minimizing the preamble overhead.

In this paper we describe the design consideration and the achievable error rate performance of several NATO standard waveform proposals for narrowband communications in tactical environments. In particular, we introduce a continuous phase modulation preamble structure consisting of two parts. First, a continuous wave (CW) section, containing N_{CW} symbols, is used to estimate both frequency and phase offset errors. This is followed by a unique start of message (SOM) sequence, with N_{SOM} symbols, used to enable accurate estimation of the timing errors. Once the unknown parameters have been reliably estimated and the appropriate correction applied to the burst packet, a header information sequence is decoded to identify the data rate and parameters of the CPM payload. In this respect, both the preamble estimation and header signal processing must be performed at relatively low SNRs. The following describes some of the key parameters and trade-offs in the design of a universal preamble.

2.0 PREAMBLE DESIGN

As mentioned, the operating point of the preamble acquisition and synchronisation is optimised with respect to the SNR requirements of the payload section of the burst communications. Specifically, Figure 1 shows the operating regions for four proposed CPM modes, with perfect acquisition parameters, for both coherent and noncoherent detection using an iterative receiver with both inner and outer codes that share decoding information through an interleaver of 25ms duration. The specific parameters of the modes are listed in Table 1. The CPM waveform of interest for preamble design is mode 1 on the left of Figure 1, which shows that the operating region in terms of the ratio of energy per symbol to noise power spectral density (E_s/N_0) is approximately 1.7 – 2.4 dB at an error rate of 10^{-4} .

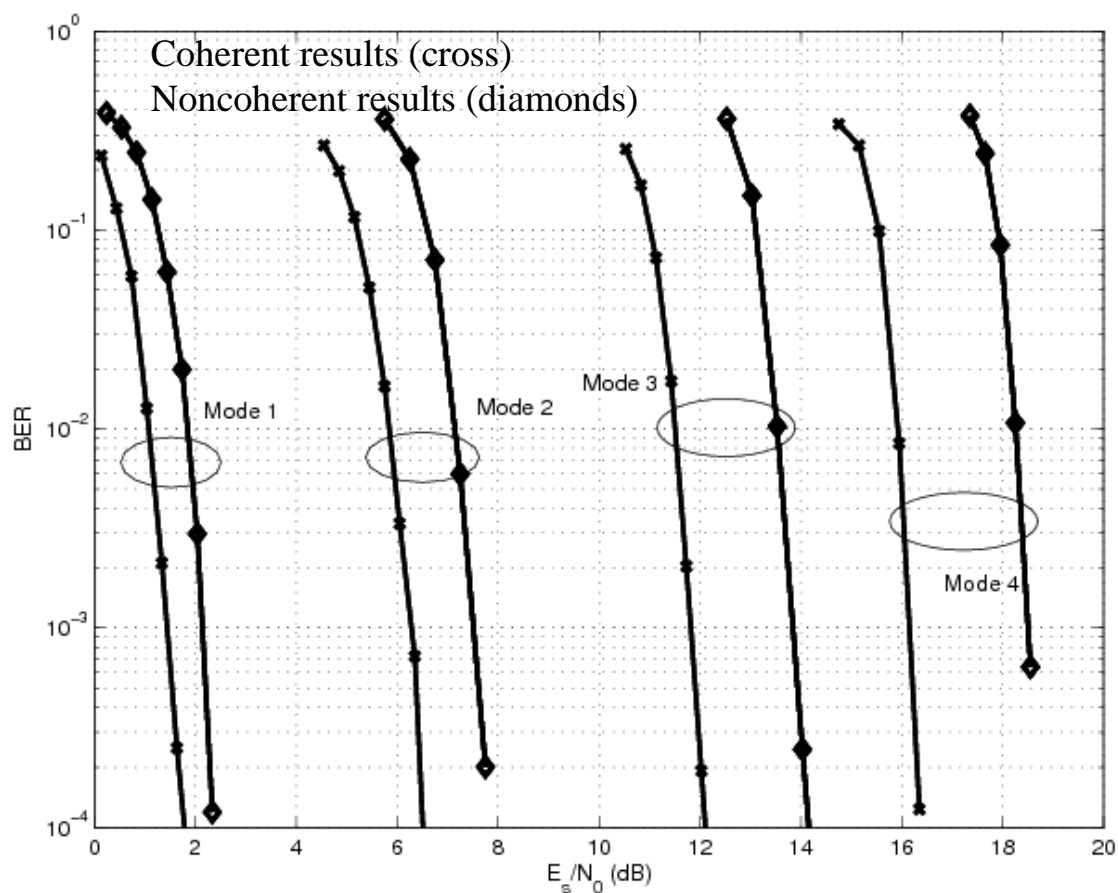


Figure 1: Bit Error Rate Performance of Various CPM Modes with Coherent and Noncoherent Detection.

Table 1: Proposed Modes for the Physical Layer of the Narrowband Waveform.

CPM Mode	Data Rate (kbps)	Code Rate	Alphabet (M)	L (Modulation Memory)	h (Modulation Index)	Pulse Shape
Mode 1	20	2/3	2	2	1/2	REC
Mode 2	31.5	3/4	2	2	1/4	REC
Mode 3	64	4/5	2	3	1/6	REC
Mode 4	96	3/4	2	3	1/11	REC

Once the operating region for the preamble has been defined, it remains to specify the accuracy requirements for the frequency, phase and timing estimation. Starting with the tolerance for the timing error, an error of $\pm T/4$, where T is the symbol period, has been shown [3] to have a negligible effect on the data demodulation for

CPM. Following the development in [2] and assuming that the estimation error for timing is Gaussian distributed over the operating region of interest, we define error reliabilities of 2 and 3 standard deviations, σ , equivalent to 95.4% or 99.97% of the timing errors within $T/4$ for the preamble SOM sequence. Figure 2 shows the relationship between the SOM length and the timing error standard deviation for the payload symbols calculated from the modified Cramer Rao bound for an unbiased estimator. The operating E_s/N_0 for the simulation results is selected as 0.2dB, which gives a noise margin of approximately 1.5dB from the lowest operating point of 1.7dB for coherent detection and allows the preamble to provide accurate estimates of the unknown parameters, prior to data demodulation. In this example, with 3σ reliability, approximately 58 preamble symbols for the SOM length are required. Selecting a length $N_{SOM} = 63$ symbols to accommodate maximal length sequences, we can now define the relationship between N_{CW} and N_{SOM} , based on the theoretical equations for the bound on the estimators. It is important to note, the requirements for the length of the preamble SOM are determined by the operating noise tolerance. The results in Figure 2 show that the selection of $N_{SOM} = 63$ symbols exceeds the requirements for modes 2-4. In particular, for 3σ reliability and a length 63 symbol SOM, the timing error standard deviation is within $T/22$ for mode 4.

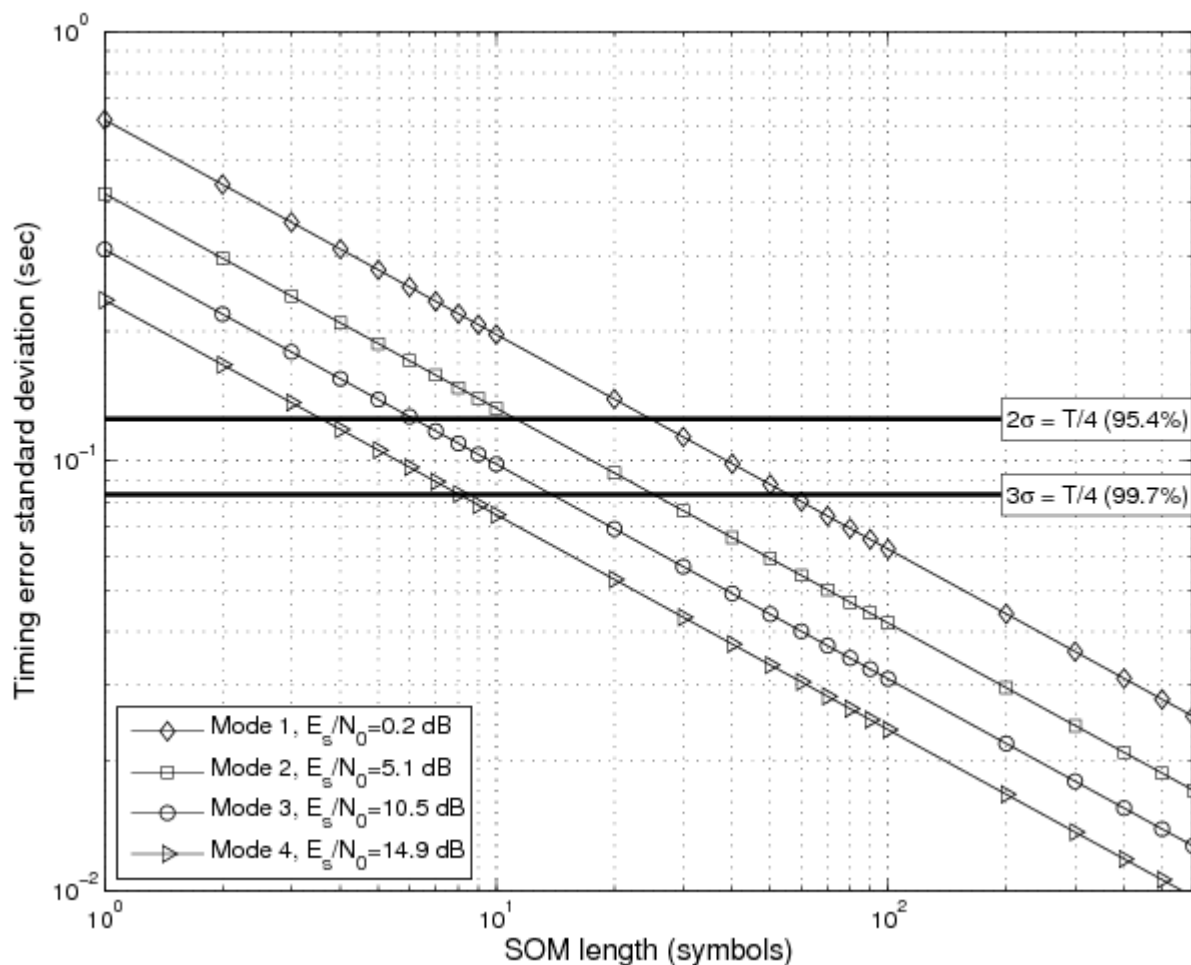


Figure 2: Relationship between SOM Length and the Timing Error Standard Deviation.

Figure 3 shows the corresponding relationship when the phase drift over the SOM sequence is limited to $\pi/2$ radians, which effectively reduces the degradation for the timing estimation algorithm. In this case, the figure shows the required ratio of the CW and SOM lengths as a function of the phase drift to achieve acceptable frame synchronisation. For 3σ reliability, the ratio is approximately 13.4 which means that $30\log_{10}(N_{CW}) - 20\log_{10}(N_{SOM}) = 13.4$ and with $N_{SOM} = 63$, results in $N_{CW} = 45$ symbols. Table 2 summarises the parameter design for the preamble and gives the overhead in terms of a 25ms burst packet duration.

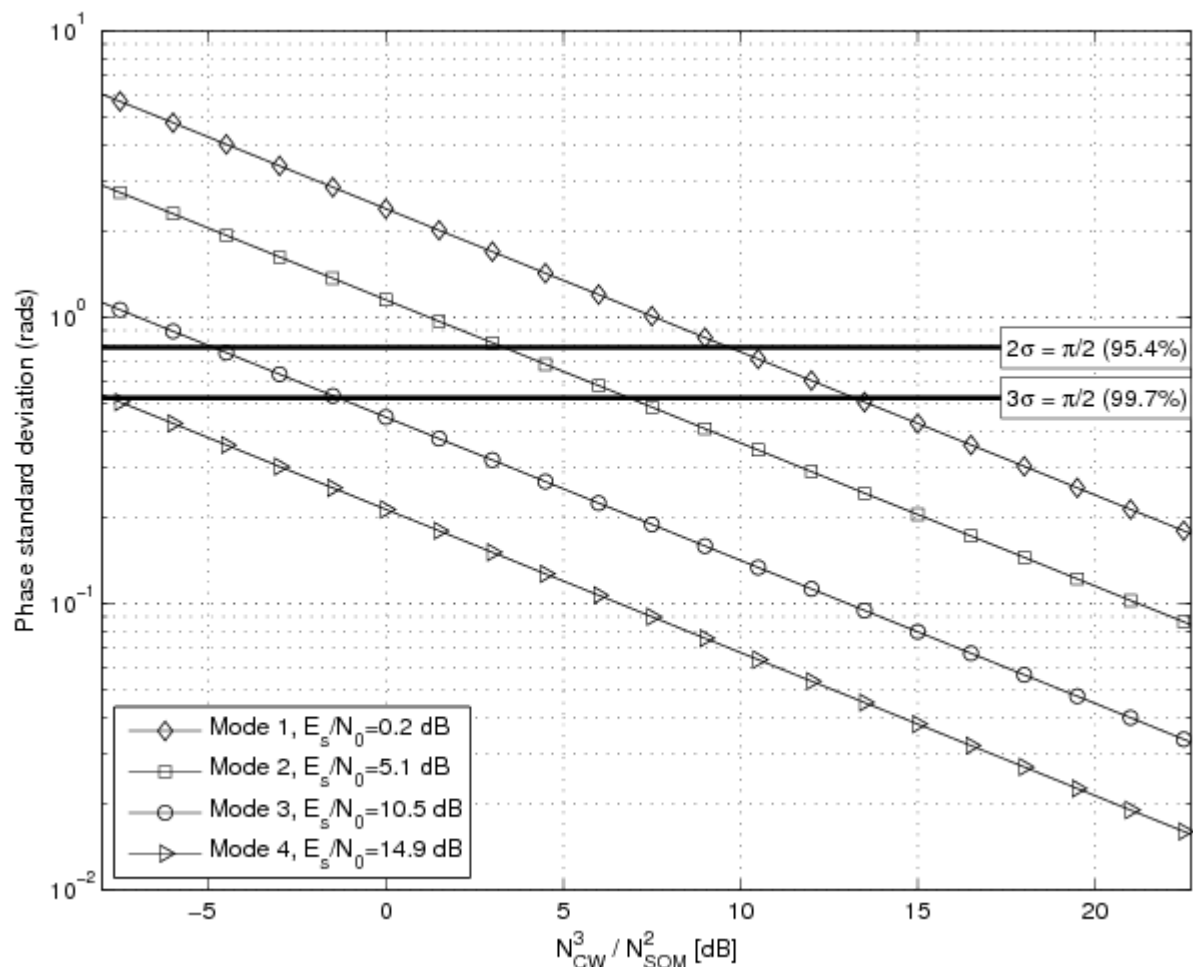


Figure 3: The Relationship of the Phase Standard Deviation to the Lengths of CW and SOM Sequences.

Table 2: Overhead for the Preamble Design, Based on a 25ms Slot Duration.

Field	Overhead %	Duration (ms)	Number of Symbols
CW	6%	1.5	45
SOM	8.4%	2.1	63
Totals	14.4%	3.6	108

3.0 SIMULATION RESULTS

Figure 4 plots the frequency offset error variance of a relatively simple iterative peak search algorithm with $N_{CW} = 45$, $N_{SOM} = 63$ compared to the modified Cramer Rao bound. As expected, the results show that the frequency estimator meets the bound for the operating region of interest. Similarly, Figure 5 shows the convergence of the phase estimation towards the modified Cramer Rao bound and illustrates the effectiveness of the phase estimation technique once the noise threshold is above -2 to -1dB E_s/N_0 .

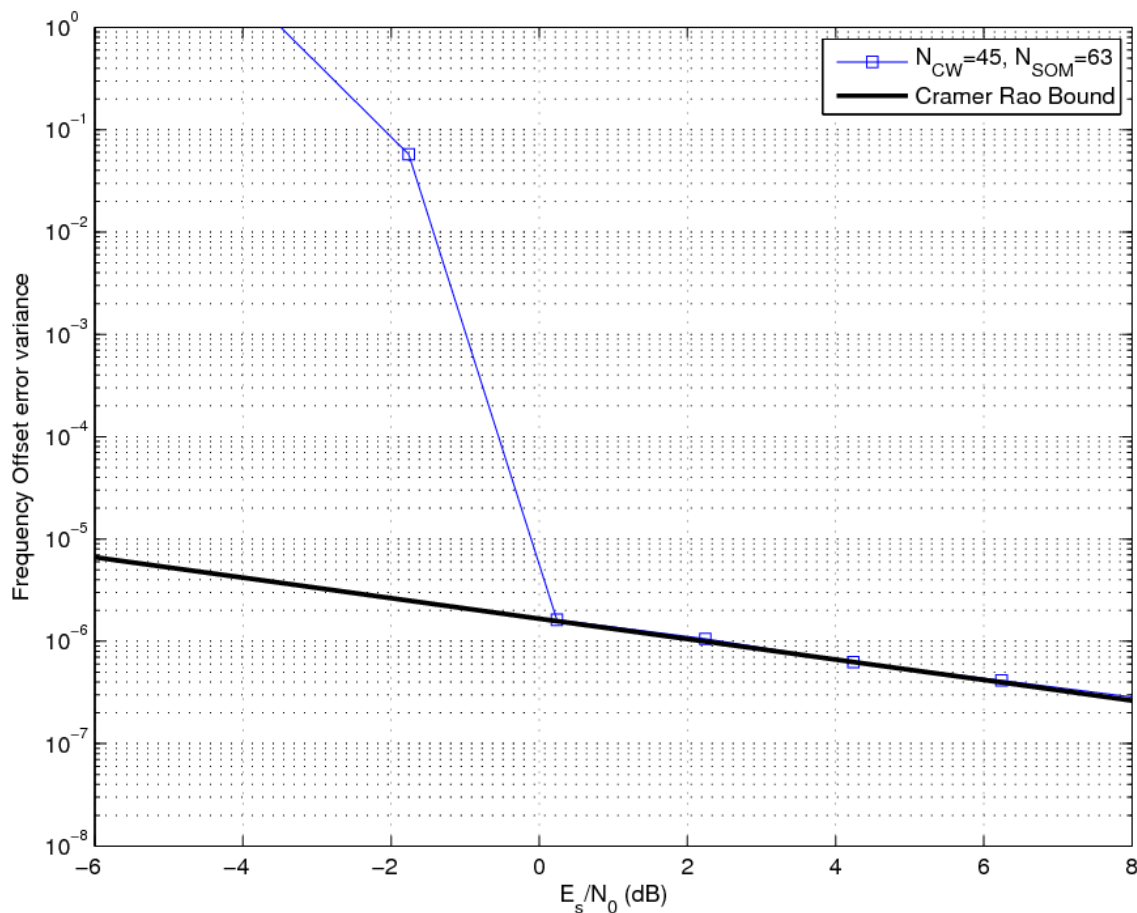


Figure 4: Frequency Offset Error Variance Showing the Performance of the Estimator Compared to the Modified Cramer Rao Bound.

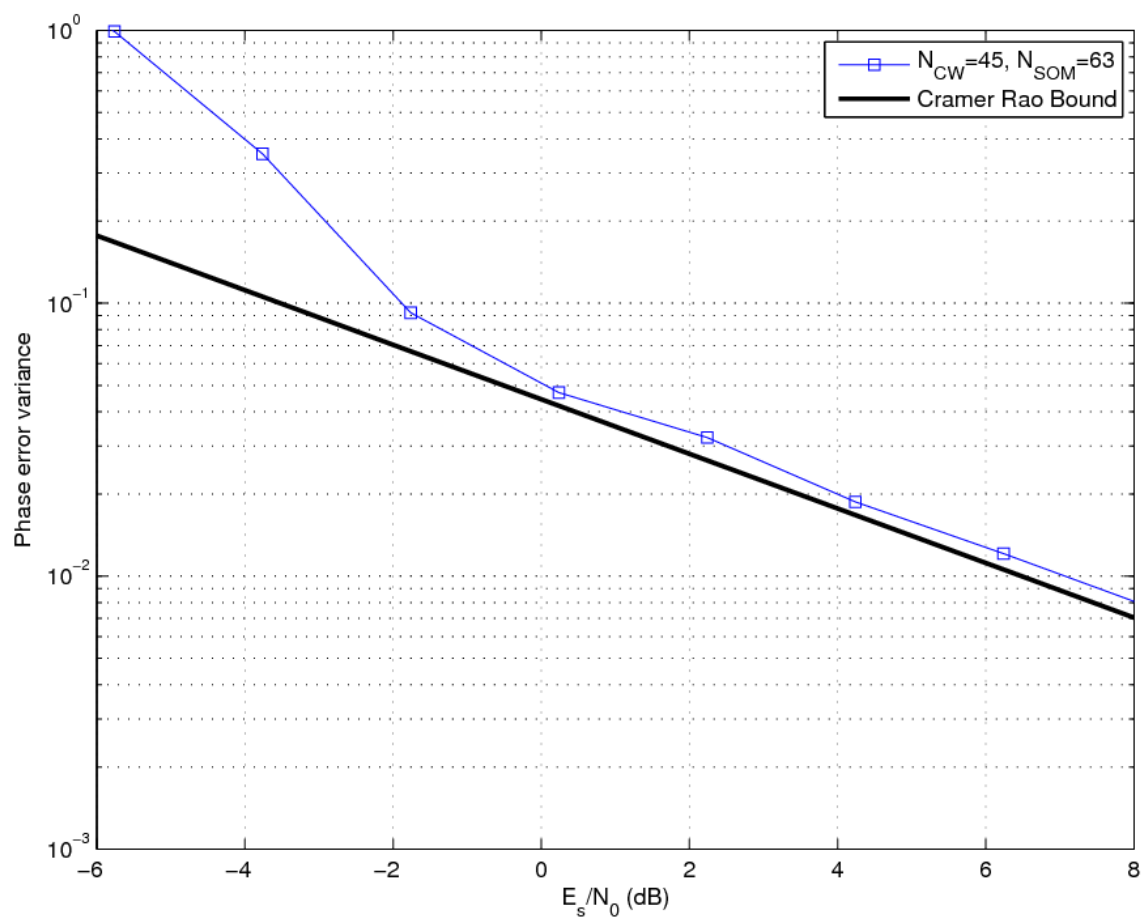


Figure 5: Phase Error Variance Showing the Performance of the Phase Estimator Compared to the Modified Cramer Rao Bound.

Finally, Figure 6 shows the performance of a correlation based estimator compared to the modified Cramer Rao bound. The latter shows that the timing based estimator operates at approximately 1dB from the bound, with the discrepancy due to the assumption in the preamble design allowing a phase drift over the SOM sequence of $\pi/2$ radians. Clearly, reducing the allowable phase drift or, in turn, tracking the phase over the SOM will effectively remove the discrepancy between the timing error variance and the bound.

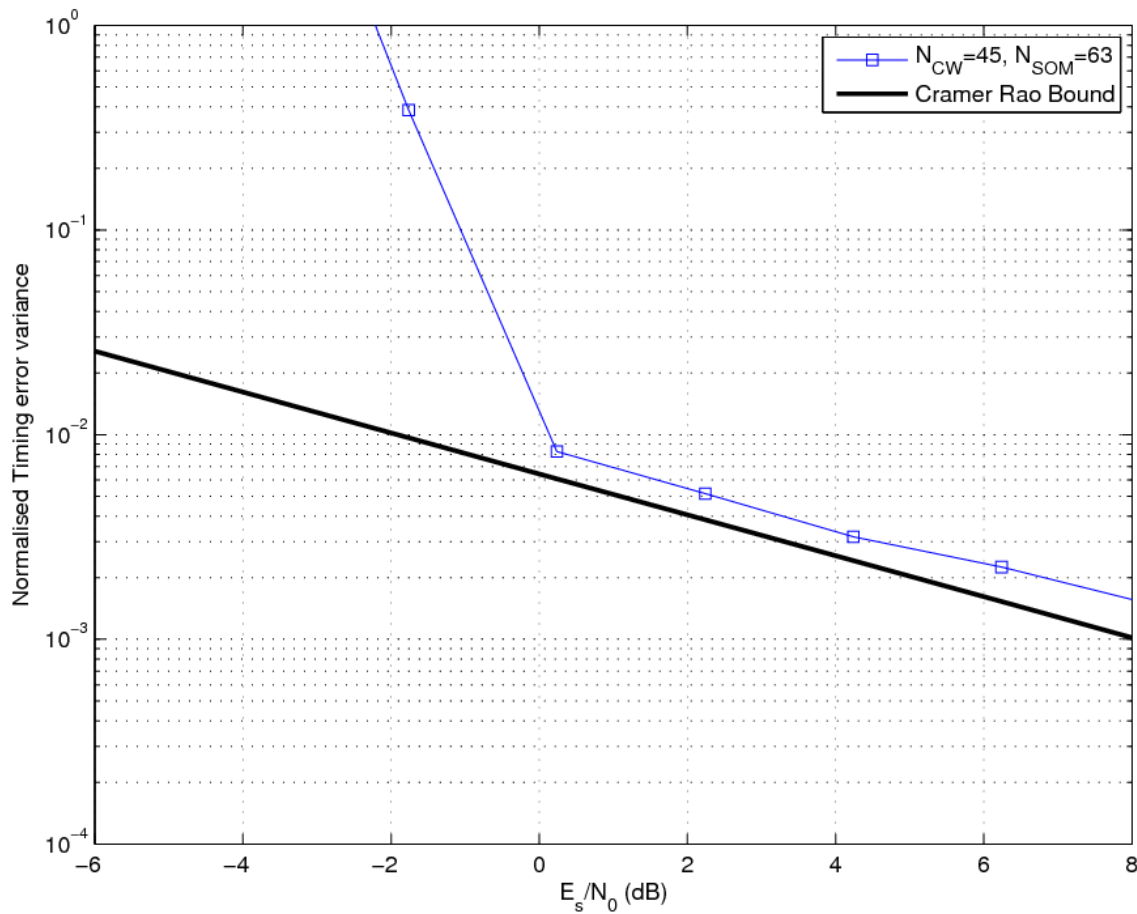


Figure 6: Normalised Timing Error Variance Showing the Performance of the Correlation Based Estimator Compared to the Modified Cramer Rao Bound.

Figures 4-6 have plotted the error variances for phase, frequency and timing errors. The results, however, do not show the impact of residual parameter errors on the bit error rate performance of the various physical layer modes. Therefore, to further verify the results for the preamble acquisition and synchronisation and to simplify the payload demodulation, Figure 7 shows the bit error rate of the payload data when demodulated with an iterative noncoherent detector. Results are compared with those of perfect synchronisation for all of the CPM transmission modes and show a negligible increase in bit error rate for all modes considered.

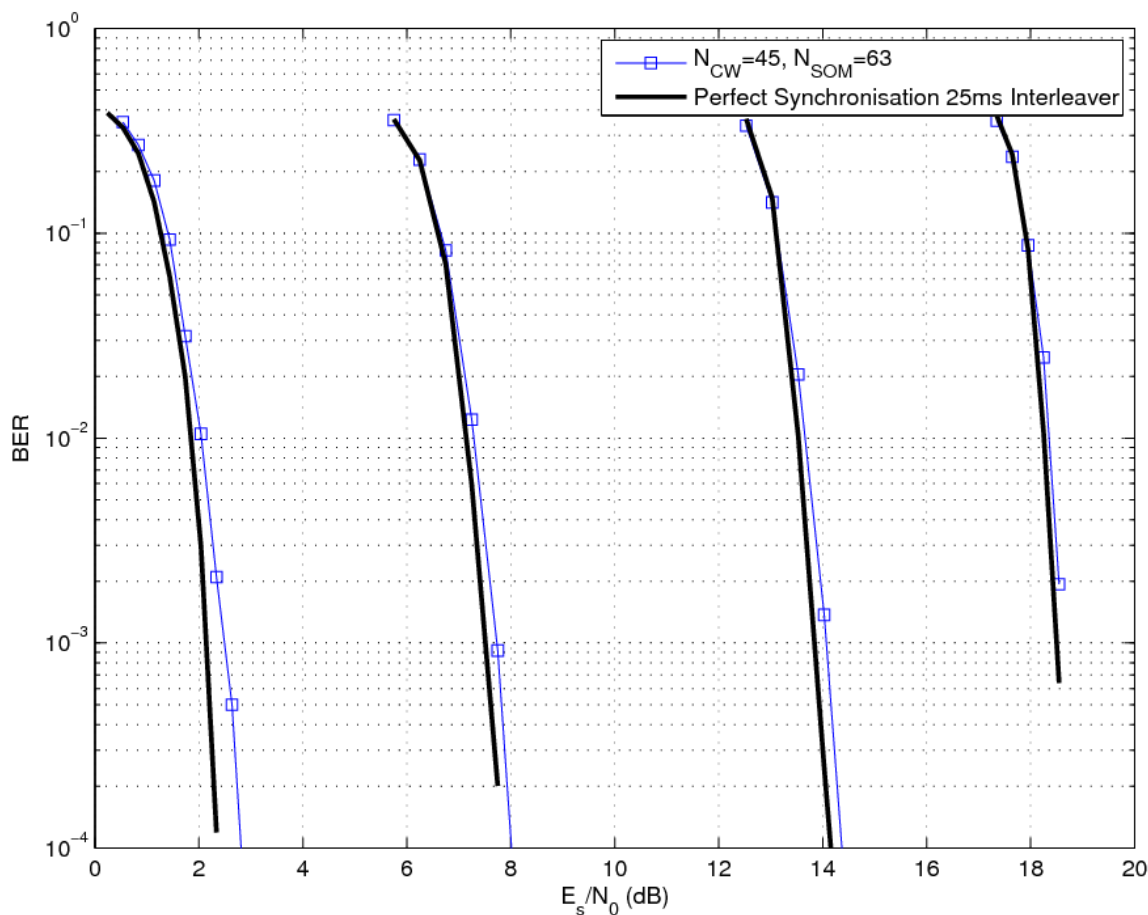


Figure 7: Bit Error Rate Performance of a Noncoherent Detector with Perfect Synchronisation Compared to the Estimation and Correction with $N_{CW}=45$, $N_{SOM}=63$.

4.0 CONCLUSIONS

An air interface waveform architecture for land tactical communications has been described, where range, throughputs and performance are significantly improved compared to legacy systems. Simulation results show that a relatively simple preamble structure for burst data communications can be used that yields excellent performance in the presence of frequency, phase and timing errors. Further, bit error rate results show little difference between perfect synchronisation and the simulated estimation and correction of the unknown parameters. In general, using noncoherent detector avoids the complexity associated with phase and Doppler tracking loops whilst still maintaining excellent error rate performance. Furthermore, after the initial timing estimate, further tracking of the timing is generally not required for burst data communications. The design approach outlined in this paper has therefore been chosen to lend itself to a simple software-defined-radio implementation of the transceiver.

5.0 ACKNOWLEDGEMENTS

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6.0 REFERENCES

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